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Chapter 11

Crewmember Nutrition

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I. Introduction

From the days of the first short-term spaceflights, providing a high-quality, balanced diet to space crews has been an important issue. Crew diet has received serious attention as one of the most important prerequisites for maintaining good health and high levels of mental and physical performance, as well as providing enjoyment to crewmembers. A nutritionally adequate diet has become increasingly important as spaceflights have grown increasingly longer and more autonomous, mission tasks have become more arduous and critical, and stressful situations have arisen more frequently. To meet these challenges, all the constituents of the onboard food supply system (which is an essential component of the life support system) have evolved from one spaceflight to the next. At the present time, onboard food supply systems, especially for relatively long-term flights, are advanced technological systems comprising, in addition to food for the crews, an "infrastructure" that allows safe storage, preparation, and consumption of food under the specific habitability conditions of the spacecraft cabin.

The initial phase of work on the problem of feeding crews in space was hampered by a lack of experience in supporting spaceflight. Previous experience with high-altitude aircraft flight, as well as simulation of spaceflights in ground-based anechoic and pressurized isolation chambers of restricted size yielded only a tentative understanding of the caloric and nutritional needs of space crews during flight. It was also necessary to solve a number of sanitary and hygienic problems relating to storage, preparation, and consumption of food in weightlessness. Furthermore, information on the functioning of the gastrointestinal tract and other human physiological systems during prolonged weightlessness was totally inadequate, since it was impossible to simulate weightlessness of appreciable duration on the ground.

The task of feeding crews during the first space flights was simplified by their short duration. Crewmembers ate a balanced diet during the preflight period, and this precluded any clinically significant levels of quantitative or qualitative deficiencies, such as lack of vitamins, protein, or minerals.

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The first orbital flights clarified our understanding of the physiology and technology of feeding crews in weightlessness and ensuring the safety of the food supply. These flights also provided the first information concerning human caloric and nutritional requirements in space. This focused and facilitated further development of onboard food supply systems.

Today, scientists have accumulated a great deal of practical information about feeding space crews on flights of up to 1 year. In addition, progress has been made with regard to the theoretical principles underlying the physiology of nutrition in space, questions of sanitation and food safety, and the technology for preparing and packaging space rations.

A number of heterogeneous medical, biological, technological, and design problems that had never been encountered on the ground have had to be solved. Onboard food supply systems are closely linked with other life support systems, especially water supply, human waste disposal, power supply, and air conditioning. At the same time, a number of serious scientific and practical problems must be solved to support future long-term autonomous flights to Mars and other planets of the solar system. Information on the dynamics of human metabolism on long-term space flights is still inadequate, in part, because of the methodological difficulties of conducting biochemical studies in flight. Complex technical problems relating to retention of the nutritive properties of food products on long-term flights remain unsolved. In addition, techniques must be developed to produce nutritionally adequate food in flight through physicochemical and biological processing of human wastes and the by-products of technological processes. Thus, a food supply system involving consumption of stored food brought from Earth will have to be replaced by systems generating food, including nontraditional sources of food, onboard. Further improvements are needed in the in-flight monitoring of space crew nutritional status in flight, including prescription of therapeutic nutritional measures, when indicated. Finally, it is becoming increasingly critical to develop rations in which food values are tailored to take account of the nature of crew psychophysical workloads and the physiological idiosyncrasies of individual crewmembers.

For purposes of discussion, the problem of feeding crews in space may be divided into the following categories:

1) Feeding space crews during short-term flights (a few

days to 1 month)

2) Feeding space crews on flights of moderate duration (from 1 month to 1 year)

3) Feeding space crews on long-term autonomous flights (over 1 year)

The first two types of space crew food supply systems have already been developed and used. However, there is no doubt that there is room for further improvement. Scientists are beginning to work on the problem of providing food to space crews on long-term flights. National programs to prepare for flights to Mars and other planets will have to intensify the research devoted to this area.

The space food supply systems developed in the United States and the Russian Federation (formerly the U.S.S.R.) have differed in their specific features as a result of differences in spacecraft and crew mission tasks; however, they share a number of characteristics, especially with respect to determining the nutritional requirements of space crews, that arise from a shared understanding of human physiology, biochemistry, and nutritional science. Exchange of scientific ideas within the framework of international collaboration on problems of space exploration has undoubtedly played a significant role in successful work on problems of space nutrition.

This chapter incorporates material we previously presented in Chapter 2, "Provision of Food and Water," of the first edition of *Foundations of Space Biology and Medicine* (Moscow-Washington, 1975), and is supplemented by reports on recent research conducted by Russian and U.S. scientists.

II. Food Supply Systems on Short-Term Flights

Food supply systems for relatively short-term flights, ranging from hours to several days, were naturally made as simple as possible, considering the sanitary and technical constraints on flight vehicles with restricted habitable areas and the need to limit the launch weight and volume of food and water supplies.

When food supply systems were developed for the first space vehicles (Vostok, Voskhod, and Mercury), it was unclear how such physiological acts as chewing, swallowing, and defecation would be affected by weightlessness. Would taste sensations alter in flight? What would be the effects of flight conditions on energy expenditure, metabolism, digestion, and human requirements for water and nutrients? How would the physiological mechanisms that regulate intake of food and water function in space?

Even for short-term flights, providing crews with a sufficient quantity of nutritionally balanced and safe food requires that food supply systems meet a number of specific criteria.

1) The rations (daily or for an entire flight) must compensate for the energy expended by the crewmembers and, to the extent possible, contain nutrients (proteins, fats, carbohydrates, vitamins, and minerals) in quantities necessary to support metabolic processes at an optimal level. This is especially true with regard to the so-called "essential" nutrients, which are not synthesized in the human body or are synthesized in inadequate quantities (these include a number of amino acids, unsaturated fatty acids, and vitamins). The products must be palatable enough to be acceptable to the space crews.

2) Unabsorbable substances in the diet must be held to a minimum to avoid putting a strain on the gastrointestinal tract, to decrease the need for waste disposal, and to make the rations more compact.

3) The volume and weight of the food products must be minimized to decrease the launch weight of the food and water supplies.

4) Crews must be able to consume their rations conveniently in weightlessness within the restricted space of the cabin. The possibility must be considered that the crewmembers may have to eat while wearing full pressure suits or while confined to their couches.

5) Food products should not require further culinary preparation, slicing, and (if possible) heating or rehydration in flight.[1,2]

6) For food supplies on short-term flights, it is preferable to use only products that can be consumed as soon as they are removed from the packaging with no further preparation. This helps to minimize the number of component parts necessary for the food supply system, limiting them to 1) an assortment of food products; 2) a container for storing them; 3) devices for preparing and consuming food (a can opener, table utensils, and a container for storing them); 4) a receptacle for disposing of and storing food wastes and packaging; and 5) a means of cleaning utensils and hands before and after eating (sterile wipes or gauze napkins moistened with disinfectant).

During short-term spaceflights, when potable water is brought from Earth, it is expedient to use standard canned food with normal water content for crew rations.

The first U.S.S.R. and U.S. spaceflights in the Vostok, Voskhod, and Mercury programs provide examples of successful compliance with the above specifications.

During preparations for the first manned spaceflights, the United States and U.S.S.R. conducted research on nutrition under conditions simulating crew work/rest schedules in flight, as well as a number of parameters of the living environment (temperature and humidity conditions, atmospheric composition) in the spacecraft cabin. This made it possible to specify space crew energy expenditure and need for the basic nutrients, and to establish the food value of flight rations. At the same time, various types of food products, methods of packaging and storage, and techniques for consuming food in weightlessness were tested.[1,3,4]

In stipulating nutritional requirements for space rations, nutritionists had to consider national recommended dietary allowances. During preparations for the first Soviet flights, the recommendations of the Nutrition Institute of the U.S.S.R. Academy of Medicine, adopted in 1951, were used. Dietary allowances recommended for adults engaging in sedentary work (the so-called first occupational category) were considered to be most appropriate for the living conditions of the Vostok and Voskhod crews. Energy expended by males, age

18 to 40, in this category at that time was estimated to be 3000 to 3200 kcal/day, and there were also recommendations with regard to needs for protein, fat, carbohydrates, and a number of vitamins and minerals.[4] These dietary allowances were refined during simulation tests on volunteer subjects and cosmonaut candidates. As a result, it was concluded that an acceptable caloric value for the first flights on Vostok spacecraft was 2500 to 2700 kcal/day.[1]

Since it was inevitable that some food would remain in the aluminum tubes used as the primary food container after the cosmonauts had finished eating, especially when the food was sticky in consistency, the caloric value of the daily ration was increased to 2800 kcal per day (available kilocalories). To facilitate assimilation of nutrients and provide uniform loading of the digestive tract, recommendations called for four meals per day, at intervals of 4 to 5 hours during the period the crew was awake.[1] An analogous meal schedule is recommended in the U.S.S.R. for the majority of the population.

For short-term flights, it was considered desirable to maintain the ratios of the basic nutrients (proteins, fats and carbohydrates) within the range recommended by the Nutrition Institute of the U.S.S.R. Academy of Medicine (1:1:3) for individuals not engaging in physical labor. The rations for the first Vostok flights contained approximately 100 g of protein, 120 g of fat, and 300 g of carbohydrates.

To prevent vitamin deficiencies associated with reliance on canned products and, possibly, increased utilization of vitamins by the body under exposure to the stress factors associated with flight, a tablet containing a multivitamin complex (C—100 mg; B_1, B_2, B_6—2 mg each; niacin—15 mg; bioflavenoids—50 mg; pantothenic acid—10 mg; vitamin E /α-tocopherol/—5 mg)[1] was taken twice a day as a supplement. There were no direct indications that there was a risk of vitamin deficiencies developing on short-term flights.

The ration constituents were tested during cosmonaut flight training in anechoic and barochambers. The caloric value of the food actually eaten in these tests ranged from 2500 to 2750 kcal/day. Assimilation of the food was estimated to be 95 percent. Convenience of packaging and taste were evaluated positively. Biochemical parameters of metabolism (protein, fat, and carbohydrate) that were typically measured to evaluate nutritional status in humans, did not differ significantly from the baseline in subjects consuming a diet of these rations.[1]

The fact that food had to be consumed under conditions of weightlessness required the resolution of a number of physiological questions. The most serious of these were 1) whether weightlessness would interfere with the processes of chewing and swallowing, 2) whether taste sensations would be altered, and 3) whether there would be significant changes in the processes of digestion and defecation. Some of these questions were answered through studies during parabolic flights of laboratory aircraft that created conditions of short-term (30-40 s) weightlessness. It was established that swallowing liquids and well-chewed food presented no difficulties in weightlessness.[5,1] These data provided a rationale for the use of only pureed products in the first Vostok flights.

Other limitations on product selection and packaging were associated with the fact that the food generally had to be consumed without additional culinary processing, such as heating. Finally, the difficulty of providing clean dishes (plates, glasses, etc.) for every meal made it desirable to use food products that could be eaten directly from their packages using only a set of utensils (spoon, fork, and knife). Thus, products had to be packaged in individual portions and divided into bite-size pieces before packaging. Eating utensils were kept clean through regular wiping with sterile wipes, either dry or moistened with a disinfectant solution (alcohol). Some limitations were imposed on selection and packaging of food to avoid contamination of the cabin atmosphere by particles of food and fragments of packaging, which, "floating" in weightlessness, could get into the respiratory tract and eyes, with undesirable consequences.

Because of the sanitary limitations noted above, cosmonaut rations for flights on Vostok 1 and Vostok 2 included only pureed and liquid products packed in aluminum tubes and subjected to thermal sterilization. Each tube contained approximately 160 g of food. The food could be eaten directly from the package and did not require heating. The following set of products was used: 1) pureed preserved food—sorrel puree with meat, meat-vegetable puree, meat, meat with grain, and prune purees; 2) pates—meat and liver; 3) juices—plum, black currant, apple, gooseberry; 4) processed chocolate-flavored cheese; 5) a chocolate dessert; and 6) coffee with milk. This large assortment made it possible to provide the varied meals necessary to maintain crew appetite and prevent crewmembers from growing tired of their food. In addition to the products in tubes, the rations contained vitamin tablets (composition listed above).

As an experiment, during the earliest flights the food container also held samples of solid foods—bread, smoked sausage, and pastry—all in bite-size pieces.[1,2]

The food system comprised an opener for removing the stoppers of the tubes, a set of sterile gauze wipes for cleaning the spout of the tubes and hands, a polyethylene bag for uneaten food, and a metal food container in which the remaining components of the system were stored according to a specified system. The food container was filled on the launch pad 1 day before launch, when the spacecraft was already attached to the booster rocket.

Yu. A. Gagarin's flight on Vostok 1 continued for 108 min (one orbit around the Earth). There was no real need for him to eat on such a short flight. However, in accordance with the research program, during min 30 of the flight, the cosmonaut consumed foods of a variety of consistencies. His conclusion was that "In weightlessness, I ate and drank, and everything proceeded just the same as at home on Earth."[1] This suggested that it would be possible to use food products varying in consistency on space flights.[1-3]

During his Vostok 2 flight, cosmonaut G. S. Titov provided more extensive information on eating in weightlessness. During a 25-h flight, he consumed his entire daily ration from tubes and tested the feasibility of consuming solid food products in a variety of packages under conditions of weightlessness.

Overall, both cosmonauts positively evaluated the food supply system. They did not experience any difficulties consuming food of a variety of consistencies or in using the packaging. No changes in taste sensitivity were noted. The short durations of the flights, of course, did not allow sufficient testing of the nutritive content of the rations with respect to the physiological needs of the cosmonauts. Gagarin's body weight decreased only slightly during the flight but did not return to normal until day 6 postflight. Titov's body weight was 1.8 kg below preflight at 9 h and 27 min after landing, and returned to normal only after 9 days.[1] It could not be established whether the decrease in body weight in both cosmonauts was caused by dehydration or dietary inadequacy.

The approach of U.S. specialists to providing astronauts with food on short-term flights in the Mercury program was analogous to the Soviet approach in many respects. The system for feeding the crews during the earliest flights was simplified as much as possible. The two astronauts participating in suborbital Mercury flights on May 15, 1961, and May 21, 1962, did not eat at all. On subsequent flights, food was consumed, in part for experimental purposes.

In the United States, initial recommendations also called for predominant use of liquids and pureed food on short-term flights. The caloric value of the ration was approximately 2500 kcal/day.[6]

Various packaging types and eating techniques were tested in weightlessness. Astronaut Glenn tested a method of eating pureed food from squeezable elastic tubes. Astronaut Carpenter tested a method for eating solid food formed into bite-size cubes. The crumbliness of solid products led to the development of an edible film coating.[7-9]

During Mercury flights on February 20, 1962, May 24, 1962, and October 3, 1962, the functioning of the gastrointestinal tract was observed when a number of meals were eaten. Rehydrated food was first tested during a Mercury flight on May 15 and 16, 1967.[10]

The studies mentioned above allayed fears that weightlessness would adversely affect processes of chewing and swallowing food.[3]

The rations for the Mercury spacecraft consisted primarily of pureed products packaged in aluminum tubes and samples of solid products. Sterile food in tubes with a net weight of 156 g each, used by Glenn, Carpenter, and Schirra on the first three manned Mercury flights, had been developed previously for pilots of the U.S. Air Force and successfully used on high-altitude aircraft flights. It is interesting that, in contrast, in the U.S.S.R., analogous products in tubes began to be used for pilots after testing in space. The Mercury astronauts consumed semiliquid meat (in tubes) and fruit (apple and peach) sauces.[11] The food was squeezed through a polysterene straw 8.75 cm in length. If the faceplate of the helmet was down, the straw was inserted in an opening in the helmet to enable eating and drinking.

Samples of solid food included compressed cubes or cakes of dry food mixtures. Malted milk tablets, cubes made of a mixture of grains, and freeze-dried fruits were also tested. The cubes were covered in gelatin. Grain and fruit cakes covered with an edible coating were also tested.

While the astronauts ate, the packaging containing the products was attached to the walls of the cabin and other free surfaces with pieces of Velcro® (a self-adhering flexible material manufactured in the United States).

During the fourth manned Mercury flight by Astronaut Cooper, the products were packed in an MA-9 container, allowing rehydration of the food. On occasion the contents leaked out into the cabin atmosphere when the container was used in flight.[12]

The rations for Cosmonaut A.G. Nikolayev (Vostok 3, August 11, 1962), P.R. Popovich (Vostok 4, August 12, 62), V.F. Bykovskiy (Vostok 5, June 14, 1963), and V.V. Tereshkova (Vostok 6, October 12, 1964), aside from the previously tested pureed and liquified products in tubes, contained a variety of solid products formed into bite-size portions and vacuum-packed in plastic pouches. The rations for the initial days of the flight of Vostok 4 and 5 contained fresh products with relatively short storage lives. Their taste was rated favorably by the cosmonauts. However, a whole series of additional measures had to be taken to maintain the quality of the products when they were manufactured, transported, and stored on the spacecraft.[2,13,14]

The caloric values of rations on Vostok 3 and 4 for the 3 days of the flight were 2480, 2846, and 2255 kcal/day, respectively. During the first and third days, the caloric value was decreased in consideration of the high-calorie diet consumed preflight and postflight. The rations contained 105-150 g protein, 64-112 g fat, and 290-325 g carbohydrates.[13] Twice a day, each cosmonaut took a multivitamin tablet: C—100 mg; B_1, B_2, B_6—2 mg each; niacin—15 mg; bioflavenoids—50 mg; E (α-tocopherol)—50 mg, and pantothenic acid—10 mg. V. Tereshkova's appetite was depressed in flight, especially for sweets.[14]

Eight hours after landing, the weight of the Vostok 4 cosmonaut was depressed by 1.8 kg and that of the Vostok 3 cosmonaut by 2.1 kg. However, 1 day later the weight loss had diminished to 0.8 kg for the latter. The rapid recovery of weight, especially in the case of the Vostok 3 cosmonaut, suggested that dehydration processes during flight had been the primary cause.[2,13] The rations used for Vostok 5 and 6 did not differ substantially from those on Vostok 3 and 4.

The flight rations of crews of Voskhod featured greater variety. The rations actually consumed by the crew of Voskhod 1 (October 12, 1964) contained approximately 3600 kcal, 150 g of protein, 130 g of fat, and 430 g of carbohydrates. Good appetites were maintained. Immediately after landing, the cosmonauts experienced intense thirst and drank avidly. Crewmembers' body weights decreased during the flight by 1.9 kg, 2.9 kg, and 3.0 kg. The short duration of the flight and the high food value of the rations makes it unlikely that the weight loss was the result of dietary deficit. The intense thirst experienced after landing, analysis of fluid balance, and results of postflight fluid loading tests indicated that water loss during flight was not adequately compensated. [2,15,16]

The crew of Voskhod 2 (March 18, 1965) also rated the onboard feeding system favorably. However, since they landed in a remote region, their postflight nutritional status could not be evaluated immediately.[2,17]

The longer orbital flights in the Gemini, Apollo, and Soyuz programs required further improvement and expansion of the space food supply systems.

The majority of Gemini flights lasted 14 days. Increased rations were needed to meet the nutritional requirements of space crews on these longer flights. It was necessary to coordinate requirements for nutritional adequacy and acceptable taste with continued strict requirements concerning weight and volume.

Work performed at the behest of NASA starting in the fall of 1963 included standardization of products and manufacturing processes and materials and designs of packages and containers. Specifications for food quality, criteria for aesthetic properties, storage life, moisture contents, tendency of fats to become rancid, physical characteristics, and microbiological specifications were developed. Optimal combinations of various types of food were also determined.

Analyses of commercial and experimental products and experience with Mercury astronauts supported the conclusion that specially prepared natural food products (particularly those with decreased moisture content, requiring subsequent rehydration) were the most stable and promising for flight conditions.[18]

Special attention was devoted to the caloric value and the levels of protein, calcium, and fluid in the rations. Here the recommendations of the National Academy of Sciences/National Research Council's Council on Food and Nutrition[19] were adopted as fundamental. In establishing minimum daily requirements and optimal ratios among amounts of protein, fats, and carbohydrates in the rations, nutritionists utilized the results of studies by Sargent and Johnson[20] and Calloway[10] concerning the physiological rationale for the diet in therapeutic nutrition. Experimental testing of prototypes of the astronaut rations in two different laboratories had positive results.[1,21,22] The U.S. Air Force also tested experimental rations on high-altitude flights.[23,24]

In the creation of an onboard system for rehydrating food,[19,23] emphasis was placed on creating convenient packaging for dehydrated products that would ensure their safe rehydration and consumption. An original package was developed in the form of a plastic bag equipped with a valve through which a tube could be inserted, which had reliability of 95 percent.

Rations on Gemini and the first Apollo spacecraft included products dehydrated through freeze drying and other methods. Some of these were compressed. A typical day's menu included approximately 50 percent rehydrated products, with the remainder being solid products rehydrated by saliva in the mouth. The solid products were eaten both during regular meals, during preparation of the products needing rehydration were being prepared, and as snacks between meals. The set of products for a typical menu for Gemini and Apollo crews during the first day of flight offers an example.

1) Meal "A"—applesauce, sugar frosted flakes, bacon squares, cinnamon toast, cocoa, orange drink (the bacon and toast were solids).

2) Meal "B"—beef with vegetables, spaghetti with meat sauce, cheese sandwich, apricot pudding, gingerbread (sandwich and gingerbread were solid, the rest had to be rehydrated).

3) Meal "C"— pea soup, tuna salad, cinnamon toast, fruit cake, pineapple-grapefruit drink (toast and cake were solid, the rest had to be rehydrated).

The total caloric value of the ration described was 2514 kcal. The net weight of the food was 580.6 g. There were four different menus with three to four meals per day. For the Gemini crews, the caloric value of the daily ration was set at 2500 kcal. The caloric value of the ration for the Apollo lunar landing crew was raised to 2800-3000 kcal per day.

On the Gemini spacecraft and the Apollo lunar module food products were rehydrated with water at a temperature of 21.1-26.7 °C; i.e., at room temperature. Rehydration took 10 min or less. The Apollo command module provided cold (7.2-12.8 °C) and hot (45.0-50.6 °C) water. The astronauts rated acceptability of the rehydrated food as higher than that of the solid products hydrated in the mouth, regardless of water temperature. The possibility of regulating water temperature raised the acceptability of the rehydrated food.

Since the rations for Gemini and Apollo used natural products and flight duration was limited to 14 days, multivitamins were not included, although, previously in the United States, it had been recommended that multivitamins be taken daily. In the opinion of Lachange,[25] it is necessary to supply spacecraft crews with vitamins, since the dynamics of nutritional status and individual needs for vitamins have not been studied adequately.

The dietary formula and the processes for preparing all forms of food for space flight are stipulated in the Flight Food Specification Document.[25] A number of works describe the technology of space food manufacture.[26,27]

As experience has been gleaned in supplying spacecraft crews with food during flight, it has become increasingly clear that to ensure the nutritional adequacy of rations we must first study the chemical composition of the food itself, as well as the dynamics of nutritional status of spacecraft crews in simulated conditions on the Earth and in actual flights.

Studies undertaken with this objective during flights of Gemini 5 and Gemini 7 on red blood cells marked with ^{14}C revealed a shortened life span for red blood cells in three of four astronauts.[28] This suggests the existence of a hemolytic state. On the last three Gemini flights, several astronauts displayed a decrease in the levels of vitamin E in plasma. This sparked scientists' interest in studying the role of vitamins and minerals in the diet of spacecraft crews.

Experience with previous space flights suggests that full consumption of products in rations is highly dependent on the sensory appeal of the food. Unfortunately, products used in flight were inferior in quality and taste to familiar "home-made" products. For this reason, the United States has devoted a great deal of attention to the taste and other sensory qualities of food for astronauts and has had some degree of success.[29] NASA has set general specifications for all food products that are stricter than those for commercial products[30] in order to ensure reliability and quality.

The United States has relied on general microbiological criteria used in sanitary practice and directed at detecting the most pathogenic food micro-organisms in conducting sanitary and bacteriological evaluations of astronaut rations.[31,32] The low level of moisture in dehydrated products and limits on the moisture content in ready-to-eat food guarantee minimal fungal contamination. Special attention has been given to methods of storing the remains of uneaten rehydrated food. On Gemini flights, 1-gram tablets of 8-hydro-oxinoinsulfate introduced into plastic pouches containing the uneaten portion proved to be adequately effective with respect to bacteriostatic action.

A great deal of attention was devoted to packaging rations. A day's ration of packaged food on Gemini weighed 725.6 g and was 2131 cm^3 in volume. When the daily caloric value was increased to 2800 kcal the ration weighed 850.5 g and had a volume of 2393 cm^3.

On the majority of flights, crews complied with mandated procedures for preparing and consuming food. The crews used individual containers, which made it easier to compute how much food was actually eaten by a given crewmember. The meal schedule was documented in a flight journal and communicated to Earth by radio. The quantity of uneaten food was subtracted to determine the total amount of food consumed.

The weight loss of the commander of Gemini 4 was 2.0 kg, and the weight loss of the pilot 3.9 kg. On Gemini 7, weight losses were 4.5 and 2.9 kg for the commander and pilot, respectively. The observed weight loss was evidently a consequence of inadequate consumption of food by the crews. During the flight of Gemini 5, food consumption was diminished, which was attributed to lack of appetite. Over the course of 8 days, the commander lost 3.3 kg and the pilot lost 3.9 kg.

Weight loss was observed in all United States and Soviet spacecraft crews on flights mentioned above. A number of authors believe that weight loss is not associated with flight duration or the amount of food consumed but is a consequence of diuresis and perspiration[33] resulting from the effects of weightlessness, especially during the initial period of the flight. However, without objective measurement of fluid balance and the amount of food consumed, this question is difficult to resolve. It has also been established that in-flight physical exercise and work in a pressure suit increase weight loss.

Attempts were made to assess the risk of nutritional inadequacy during flight by computing an indicator of food consumed and measuring the amount of released CO_2 adsorbed by lithium hydroxide in special canisters. When this method was used on Gemini 5, it was found that about one half of the astronaut's weight loss could be attributed to caloric deficit.

To prevent bone demineralization and support calcium balance, calcium lactate was added in fruit juice to the rations of certain crews. This made it possible to increase the amount of calcium ingested by Gemini 7 crews to the required level—approximately 950 mg/day.

The major components of the food supply system in the Apollo program were adopted as the basis for the feeding system for Skylab.[34]

Soyuz spacecraft did not have facilities for rehydrating food. Therefore rations consisted mainly of canned natural, rather than dehydrated, products of various consistencies (Fig. 1). Products with diminished levels of moisture were held to a minimum. The rations included products that had proved acceptable in previous flights: pureed soups, creamed cottage cheese, and drinks of cocoa and coffee in aluminum tubes, some of which could be heated in a special device (Fig. 2). Black currant juice, rich in vitamin C, stored in a special container was used. There was a large assortment of canned meats in metal cans. *Rossiyskiy* processed cheese was also packed in such cans. The rations also included various types of bread—*Stolovyy*, *Borodinskiy*, and *Rizhskiy*. Bread products were formed into small bite-size pieces and packed eight to a polyethylene film package. A packet of bread for a single meal weighed 50 g. Desserts included chocolate with a high melting point, honey cakes, fruit jellies, and prunes with nuts. All products in plastic pouches were divided into bite-size portions. Some of the products in the pouches were vacuum packed.

Daily rations for cosmonauts included two multivitamin tablets, called *Undevit* (A—3300 I.U., B_1—2.58 mg, B_2—2 mg, B_6—3 mg, B_{12}—12 mg, C—75 mg, E—10 mg, nicotinamide—20 mg, folic acid—0.5 mg, calcium pantothenate—3 mg, and rutin—10 mg).[35-37]

There were three variants of the daily rations, creating a 3-day menu cycle. An example of the daily ration is as follows:

1) Breakfast: ham (canned), *Borodinskiy* bread, chocolate candy with walnut praline, coffee with milk, and black currant juice.

2) Lunch: beef tongue (canned), *Rizhskiy* bread, and prunes with nuts.

3) Dinner: dried salted fish, borshcht, veal (canned), *Stolovyy* bread, pastry, and black currant juice.

4) Supper: creamed cottage cheese, candied fruit, and black currant juice.

The weight of a day's ration without the packaging was approximately 1460 g, with a caloric value of approximately 2800 kcal—139 g of protein, 88 g of fat, 345 g of carbohydrates, and 853-950 ml of water. The ration contained minerals in accordance with the general physiological nutritional norms adopted in the U.S.S.R. The caloric value of the ration was distributed as follows: breakfast—26 percent,

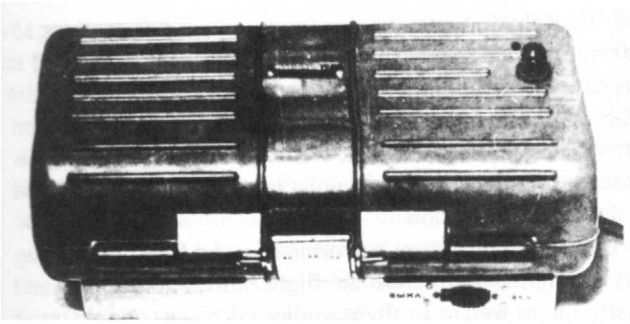

Fig. 1 Exterior view of the Soyuz food tube heater.

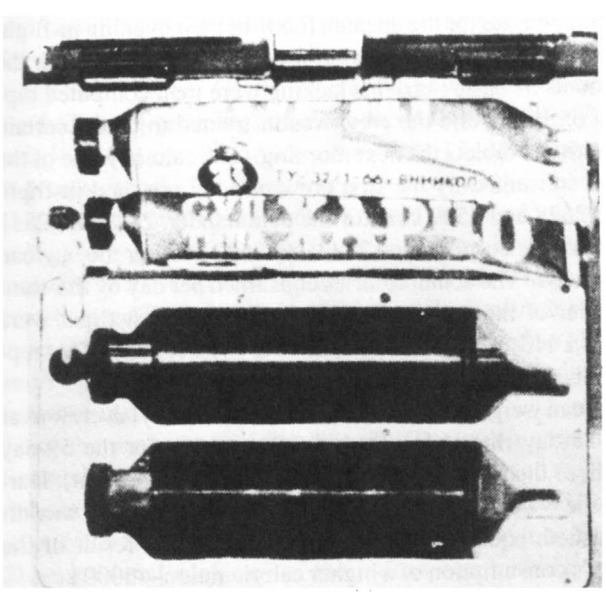

Fig. 2 Food tubes in the heater.

lunch—21 percent, dinner—30 percent, and supper — 23 percent. In ground tests the assimilability of the nutrients was found to be 90 percent for protein, 97 percent for fats, 96 percent for carbohydrates, and 95 percent for calories. Cosmonauts flying on Soyuz rated the products in the rations as good.[35-40]

The rations on the U.S. Space Shuttles include thermostabilized, rehydratable, and partially dehydrated irradiated natural (fresh) products. The majority of products are packed in metal containers with nitrogen, and are similar in form to commercial products. The mean caloric value of a day's ration is approximately 3000 kcal, and the weight of the food before dehydration is 2.4 kg and after dehydration about 1.1 kg. Food is rehydrated with hot and cold water. The food values of the rations, on the whole, comply with the dietary recommendations of the Council on Food and Nutrition of the National Academy of Sciences (see Figs. 3 and 4).[41-43]

III. Food Supply System for Space Flights of Moderate Duration

Support of space flights of moderate duration (from 1 month to 1 year) required significant improvement of the previously developed and space-tested components of the

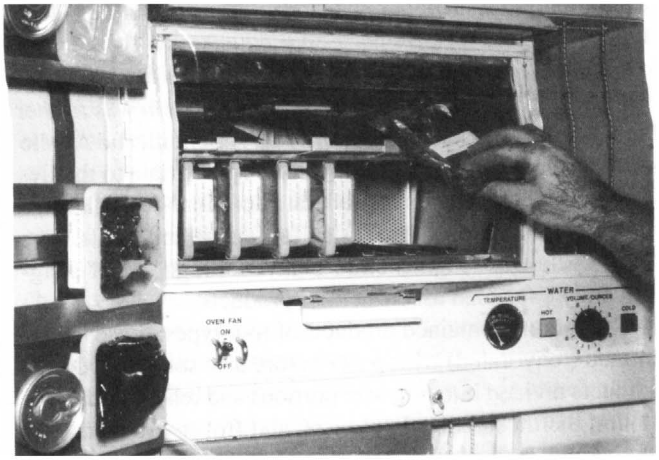

Fig. 3 Shuttle food system (NASA S82-26424).

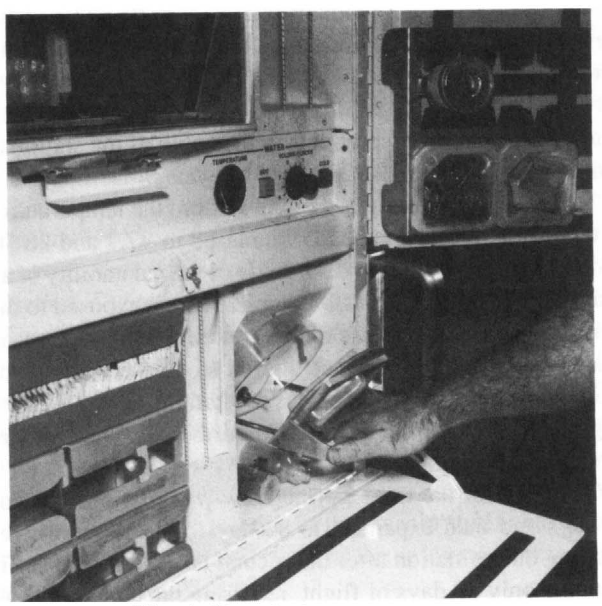

Fig. 4 Shuttle food rehydration device (NASA S82-26423).

onboard food supply system, as well as the introduction of new components. The most important task was improving the food value of the rations to support crew physiological needs on longer and more autonomous flights. It was important to expand the assortment of products and offer forms that would prevent the crews from growing tired of the food. Individual habits and preferences of the crewmembers had to be considered more carefully. It was essential to substantially increase the period over which the products retained their taste and other palatability factors, and to maintain the quality of the products in the rations. To make meals more pleasant, more foods had to be heated, the proportion of solid and dry products has to be decreased, and the resemblance of mealtime conditions and eating methods to those typical on Earth had to be increased. Meals had to become a source of enjoyment. Means of in-flight monitoring of crew food consumption and nutritional status also required further attention.

The U.S. Skylab crews remained in space for as long as 12 weeks. Skylab's onboard food supply system was further improved over the one used on Mercury, Gemini, and Apollo spacecraft and was significantly more appropriate to the living conditions on flights of moderate duration. A special 9.3-m^2 area in the cabin was set aside for leisure and meals. The menu cycle was lengthened to 6 days through use of a significantly expanded assortment of products.

The rations contained products of four types: those reconstituted (rehydrated) with water before use; solid dehydrated products divided into bite-size portions and rehydrated in the mouth; thermostabilized products; and frozen products. All food products (aside from drinks and puddings) were packed in aluminum cans. Drinks were packed in polyethylene accordion folded packages. The packaged products were stored in aluminum canisters.

The majority of the products intended for the three crews were stored onboard the station in 11 lockers at room temperature, in 5 lockers at a temperature of -18° C and below for deep frozen products, and in one refrigerator. The guaranteed shelf life of the products in the cabin of the station at room temperature (about 29 °C) was 2 years.

Unfortunately, during use of the station, the temperatures in the dining area periodically increased to 37.7 and 58 °C and, in the freezer to -8.3 °C. A study of the palatability of an analogous set of products stored on Earth and exposed to the same temperatures as those on the station showed decreased quality in 16 samples. Since altered storage conditions of products in flight may lead to loss of vitamins, it was decided to give members of the second and third crews vitamins before, during, and after flight.

The flight of the third Skylab crew was first planned for 56 days and then expanded to 84 days, but the rations remaining on the station after the second crew left were sufficient for only 69 days of flight, requiring the delivery of an additional 72 kg of products. However, specialists in nutrition managed to decrease this weight to 27 kg by using concentrates with increased caloric values of 3000 kcal/day. The assortment contained 70 different products. Daily rations were selected from these products, and menus were developed with consideration of the individual taste preferences of the crewmembers. This measure helped match the food to individual tastes, making it less likely that crewmembers would tire of their rations. The mean daily ration had a caloric value of approximately 3000 kcal and contained about 150 g of protein, 120 g of fat, 320 g of carbohydrates, 0.8 g of calcium, 2.2 g of phosphorus, 6.3 g of sodium, 4.3 g of potassium, and 0.32 g of magnesium. The weight of a day's ration was 1.9 kg, and the volume was 5.7 liters.[44] The food ration on Skylab was rather close in food value to that used on Salyut 6.[35,37,44]

Food was prepared and consumed at a special table, which contained heating trays and water guns for rehydrating the food and dispensing drinking water. The food was heated to 65 °C. Rehydration of certain foods required as much as 15-20 min, which meant that one of the crewmembers had to prepare the meal in advance. The products eaten hot were placed on the heating trays and the cold products in a chiller. After meals, the trays and table were cleaned with moist wipes. Utensils were cleaned with moist terry cloth towels soaked in disinfectant solution.

Balance studies were performed for the first time during Skylab flights. Astronauts ate flight rations during pre- and postflight, as well as in-flight studies. When a component of the ration could not be eaten, a system of rapid computation was used to prescribe dietary supplements of mineral tablets to compensate for the uneaten food. In their evening in-flight reports, the crew related what food had been consumed; the amounts of basic nutrients lacking were then computed rapidly on Earth, and the crew was instructed to take a certain quantity of tablets the next morning. The caloric value of the food consumed by the first crew per day pre- and in-flight was 2628 and 2509 kcal for the commander, 2822 and 2517 kcal for the co-pilot; and 2843 and 2593 kcal for the payload specialist. The actual calories consumed per day by the commander of the second crew, pre-, in-, and post-flight were 2732 ± 113, 2781 ± 259, and 2940 ± 149 kcal/day. This represents 40, 41, and 43 kcal/day per 1 kg body weight.

Mean weight loss in members of the first Skylab crew over the 28-day flight was 2.9 kg (3.9 percent); for the 59-day flight of the second crew, loss was 3.2 kg (4.6 percent). During the 84-day flight of the third crew, weight loss was diminished, equaling 1.1 kg (1.6 percent), as a result of the crew's consumption of a higher calorie ration—3000 kcal —and more physical training exercises. There is reason to believe that the third crew managed to maintain their preflight nutritional status.

The metabolic processes of Skylab crews were monitored pre- (on days 31, 27, and 21), in-, and postflight (on days 17, 18, and 18) for crews 1, 2, and 3, respectively. As had been the case for other flights, crewmembers experienced weight loss, accompanied by increased excretion of nitrogen, calcium, phosphorus, magnesium, and potassium.[35, 37,45,46]

Salyut 6 (September 29, 1977) utilized an improved food supply system, compared to those used on Vostok, Soyuz, Apollo-Soyuz, Gemini, and Salyuts 1 through 5. The system included rations; food storage containers; a dining table; an electric heater; utensils; devices for water regeneration, measurement, and dispensing of hot or cold water into the plastic pouches containing the rehydratable food; and receptacles for food scraps and discarded packaging. The cosmonauts cleaned their hands before eating, and utensils were cleaned using moist wipes with antimicrobial properties.[17,35,37,47-49]

The caloric value of the cosmonauts' rations was increased to 3150 kcal/day because of the expansion of the prescribed set of physical training exercises, which had proved effective in preventing the negative consequences of long-term hypokinesia and weightlessness. The rations, on the average, contained about 135 g of protein, 110 g of fats, 380 g of carbohydrates, 0.8 g of calcium, 1.7 g of phosphorus, 0.4 g of magnesium, 3.0 g of potassium, 4.5 g of sodium, and 50 mg of iron. On the flight of the first crew, cosmonauts took *Undevit* multivitamin tables (composition described above) twice a day. Starting with the flight of the second prime crew, *Aerovit* multivitamins (vitamin A—6600 I.U., B_1—2.58 mg, B_2—2 mg, B_6—10 mg, B_{12}—.025 mg, calcium pantothenate—10 mg, vitamin C—100 mg, vitamin E—20 mg, nicotinamide—15 mg, rutin—50 mg, and folic acid—0.5 mg) were used since they were more stable under storage. *Aerovit* had first been tested on Salyuts 3 and 5.

The mean weight of the daily ration was 1.7 kg, and its volume was 465 liters. The assortment of products and dishes was significantly expanded (from 44 on Salyut 4 to 70 on Salyut 6), which made it possible to switch from a 3-day to a 6-day menu cycle. On the whole, the new rations retained the traditional groupings of products: meats—25, dairy—5, bread—5, pastry—10, fruits and juices—12, hot drinks—3, and seasonings—2. There was a greater selection of heatable products and dishes in tubes, cans, and plastic wrap. A system for regenerating water from condensate of atmospheric moisture (SRV-12) made it possible to include a large number of freeze-dried entrees and drinks, which were reconstituted in their packages with hot water. The selection of fruit and vegetable juices reconstituted with cold water obtained from the water supply receptacles was increased. A total of 34 of the products could be heated. The crews responded favorably to this "innovation". Crewmembers noted that they did not grow as tired of the products, which retained their palatability for a longer period of time than on previous flights. The nutritional adequacy of the rations was initially determined under simulation conditions on the ground and, later, by evaluating parameters of cosmonaut nutritional status pre- and postflight, using data from clinical and physiological examinations postflight, and cosmonaut reports.[17,37,47-49]

Supplementary food products delivered to orbit by the Progress cargo vehicle and Soyuz and Soyuz-T transport spacecraft helped to solve the problem of feeding crews of Salyuts 6 and 7. The five prime crews of Salyut 6 were provided a rather wide selection of products and dishes (fresh vegetables and fruits, fruit and berry juices, seasoning, drinks, newly developed dehydrated and canned products), taking into account individual preferences. There was almost always a surplus of food products (flight rations plus supplementary products) onboard Salyut 6.

Despite this, of the 10 cosmonauts participating in the 5 prime crews, the majority—7 individuals—lost weight in amounts ranging from 1.8-6.4 kg, while the 3 others gained weight (0.2-3.5 kg) over the course of the flight. A number of authors explain changes in body weight by hypothesizing that individuals vary in their susceptibility to flight factors, in metabolism, and in the zeal with which they used prophylactic countermeasures. In particular, all members of the fourth prime crew, who strictly observed all prophylactic countermeasures and actively utilized such appetite enhancers as onion, garlic, and spices, gained weight. A study of parameters of nutritional status pre- and postflight did not reveal any significant changes in the cosmonauts.[37,48-52]

In general, the onboard food supply system for the long-term space station Salyut 7 (April 19, 1982) generally contained the same elements as that of Salyut 6, with the exception that, for the first time, there was a refrigerator for storage of fresh fruits and vegetables. A flight ration developed for the Salyut 7 crew was approximately the same in food value as that for Salyut 6 but consisted primarily (65 percent) of dehydrated products reconstituted with hot or cold water. This change was based on the experience of Salyut 6 crews, who received rations consisting of only 20 percent freeze-dried products, while the remaining 80 percent were primarily thermostabilized products. At the end of the second month of flight, the cosmonauts noted that they were growing tired of the sterilized products. The majority of dehydrated products included in the Salyut 7 ration had been tested in previous flights as supplementary products delivered to orbit by the transport vehicles. During the flights of the three Salyut 7 prime crews (211, 150, and 237 days in duration) all components of the food supply system functioned normally. The cosmonauts concluded that the rations helped them maintain a performance level adequate for completion of the flight program.[37,49,53]

A new menu-selection system for organizing flight rations was used for the first time on Salyut 7. In essence, this system involved packing the products in containers with other products of the same kind, rather than packaging a day's meals together. The new system facilitated tracking of the quantity of products used and allowed crewmembers to compose each meal on the basis of individual tastes. In practice, the crewmembers were frequently guided by their taste preferences, which did not always lead to a well-balanced menu with respect to food groups. Experience with the menu-selection system indicated that its success depended in many respects on preflight training of the crew in nutritional theory. The postflight nutritional status of the cosmonauts was, however, satisfactory.[49,53-55]

A record-setting space flight lasting 1 year was accomplished by a crew consisting of B.G. Titov and M.Kh. Manarov on the long-term space station complex Mir-Soyuz-TM-Kvant-Progress (December 21, 1987 to December 21, 1988). The onboard food supply system was, on the whole, analogous to that on Salyut 7. The rations consisted of 65 percent freeze-dried products that were reconstituted before use with hot or cold water, regenerated from humidity condensate, or brought from Earth. Since the products in standard flight rations are not recommended for storage for lönger than 10 months, the Progress transport spacecraft delivered additional flight rations and drinking water requested by the crews, along with fresh apples, lemons, oranges, onions, garlic, cucumbers, honey, and other products with limited storage life. These measures substantially improved the crew's appetite and frame of mind.

On the whole, the cosmonauts evaluated the food supply system positively and willingly ate most of the products. No significant changes were noted in taste sensitivity, appetite, or digestive function.

After the 1-year flight, the commander lost 3.3 kg. During postflight clinical observation, his weight was observed to be 2.7 kg below baseline on day 4, and 0.5 kg below baseline on day 16. The flight engineer gained 2.1 kg. On day 16 postflight, his weight had returned to its preflight level. On the whole, over the 1-year flight, changes in weight were no greater than for shorter flights. With respect to anthropometric and biochemical parameters, no notable changes were found postflight. All this suggests that the rations used in flight, combined with the supplementary products regularly delivered to the station in orbit, proved adequate for the needs of the cosmonauts. The entire food supply system also proved efficient throughout the year.[56]

IV. Provision of Food for Long-Term Flights

There have not been any long-term space flights with durations greater than 1 year. In the future, plans call for the creation of a new generation of orbital stations, an expedition to Mars, and the establishment of planetary bases on the Moon and other celestial bodies of the solar system. All these and other permanently manned spacecraft require life support systems that are reliable and can function efficiently for several years. In particular, crews of these spacecraft and stations will need regular, well-balanced, and safe food to maintain their health and a high performance level throughout their missions.

Experience with previous space missions of up to 1 year suggests that, during space flight under relatively comfortable sanitary and hygienic conditions, the human body generally needs the same amounts of nutrients as on Earth. For this reason, the physiological nutritional norms for various demographic groups developed in the United States and the Russian Federation are acceptable for use in planning food supply systems for long-duration missions. Incidentally, within the limits of the stipulated age groups, these norms are valid for indefinite periods. Of course, during specific periods in flight, the amount of one or another nutrient needed and their optimal ratios in food may change, and this requires further study.

However, matters become more difficult when we turn to the issue of supplying space crews with high-quality, chemically well-balanced, and tasty food—a reliable source of the necessary quantity of energy and nutrients, especially essential nutrients. This is particularly true with respect to flights to other celestial bodies, when it becomes impossible to supplement onboard supplies with fresh products. Here, it seems promising to consider storing products in freezers and refrigerator chambers. However, refrigeration equipment has significant weight and volume and requires a significant expenditure of power, which is limited in flight. For this reason, as space flights become more autonomous so that onboard food supplies cannot be supplemented, the issue of guaranteed long-term storage of products in flight becomes more critical. Much work awaits us in this area.

The entire system of food preparation and consumption requires further improvement to make these processes more convenient, safer, easier, and less time-consuming. It is also necessary to improve the system of sanitary and antiepidemiological measures—those associated with the food supply technology, with the cosmonaut himself as a source of microbial contamination, and with prevention of contamination of the environment by food products.

Feeding ill crewmembers and dietary rehabilitation under conditions of altered physiological status and in emergency situations are other important topics.

The majority of authors writing today consider freeze-dried, vacuum-packed, and frozen products and dishes to be the most promising for use on long-term flights. Many countries are developing a wide assortment of such products, studying the best conditions for storing them (temperature and atmosphere, packaging, etc.), and evaluating their food value.[44,57-62] Development of food rations from freeze-dried products for long-term flights requires, first, the resolution of the following issues:

1) Is it possible to maintain good nutritional status on a diet based on dehydrated products and other preserved products over a long (2-3 year) period and evaluation of the nutritional acceptability of various degrees of rehydration?

2) What are the effects of long-term storage (2-4 year), with possible exposure to doses of cosmic radiation, on the food values and properties of dehydrated products?

3) What packaging is the most appropriate to storage conditions and safest from the standpoint of the products themselves, as well as the environment?

4) What types and assortments of dehydrated, frozen, irradiated, and other products are suitable with respect to physiological and hygienic parameters and palatability?

To solve some of these problems, the Russian Federation is conducting research studies continuing for as long as 1 year and using volunteers. The subjects consume a diet consisting totally of freeze-dried products under normal living conditions or in a sealed chamber (1 year). In three other experiments, subjects have received rations that were stored for 1-2 years with a portion irradiated by protons in a dose of 24,000 rad. The rations contain 3100-3200 kcal, 130-140 g of proteins, 96-125 g of fats, and 340-430 g of carbohydrates. Each subject takes a *Undevit* multivitamin tablet daily.[17]

All subjects undergo clinical medical monitoring. Parameters of protein, lipid, carbohydrate, vitamin, and mineral metabolism, the status of the gastrointestinal tract, the balance of a number of nutrients, and assimilation of the major nutrients are studied. Immune response and composition of intestinal microflora are also studied.[17]

The results of these studies support a conclusion that long-term (more than 1 year) human consumption of a diet consisting entirely of dehydrated products is possible, with adaptation requiring approximately 2 months.[17]

The results of consumption of dehydrated products after long-term storage and irradiation by protons were positive. The nutritional status of the subjects was evaluated as satisfactory, but at the same time it was deemed desirable for individuals on flights of as long as 2 years to take an *Undevit* multivitamin once a day, along with no less than 40 mg of vitamin E, 1 mg of vitamin A, and 0.5 g of calcium. These recommendations are based on results of measuring vitamins A and E in blood serum, and the discovery of symptoms of negative calcium balance.[17]

Nevertheless, as the durations of autonomous space flights increase beyond 2-3 years, the use of a food supply system based solely on supplies of food brought from Earth will become increasingly problematic. This raises the question of using various physicochemical and biological methods to extract nutrients from human wastes and by-products of various technological processes occurring in the onboard systems of the spacecraft. These issues have occupied researchers since the first short-term space flights.[63-65] Considering the aspects of the problem of providing food on long-term flights noted above, one may define the following possible basic types of system for feeding spacecraft crews.

1) Systems based exclusively on supplies of food brought from Earth. Considering the capabilities of modern food technology and the characteristics of the products and packaging that have been produced, an onboard food supply system of this type appears completely feasible for long-term flights with duration of 1, 2, and even 3 years. Thus, such a system is completely feasible for use on Mars flights. Of course, before such a system is approved for practical use in flight, considerable technological and design work and significant biomedical research will be needed to evaluate long-term storage of rations in simulated ground-based and flight conditions.

2) Mixed-type systems, in which space crews on long-term flights primarily use food supplies brought from Earth in the form of ready-to-eat products or preprocessed products requiring some additional culinary processing before use. As a supplementary source of nutrients, this system could use nutritive material obtained from processing crew wastes and by-products of technological processes of other spacecraft systems. For this purpose, the spacecraft must have special systems for obtaining this material from wastes through physicochemical and biological methods, and technological equipment for obtaining ready-to-eat food or individual nutrients from these nutritive materials, including those from nontraditional sources. The creation of reliable and relatively productive systems as components of onboard life support systems for transforming wastes into food products is still in the early stages. The task has proved to be more difficult than was initially thought. There has been some success in developing onboard greenhouses for growing algae. However, even here a great deal of additional work is needed, both in the technology for growing biomass and in the processing of this biomass into assimilable products. Use of the biomass in its raw form is limited in quantity by the biological, physiological, and psychological characteristics of humans. On flights lasting 1 to 2 years this issue is not critical but it would be very important to begin to test it.

3) Food supply systems primarily using food obtained from processing wastes, through the use of chemical, physical, and biological methods by onboard technological systems. Even for these systems to provide an adequate diet, certain essential nutrients would still have to be brought from Earth. These include vitamins, polyunsaturated fatty acids, amino acids, minerals, and spices and seasonings, which are too difficult to produce in the onboard systems of the spacecraft and of which relatively small amounts are required to meet physiological needs.

Under certain conditions, it would be possible to periodically supplement systems of the second or third type with additional supplies of food. At the present time, onboard food supplies to orbital stations are systematically supplemented, sometimes during crew exchange. Food products to meet the individual tastes of crewmembers have been delivered to space stations in orbit.[53,57,66]

However, creation of onboard food supply systems based on the use of food resources produced in flight as a result of waste processing remains an extremely complicated task. In the previous edition of "Foundations of Space Biology and Medicine," [2] the use of such food products in flight was considered in detail in Volume III, Chapter 2.

First, the chapter considered the use of physicochemical methods to produce food or rather individual nutrients: carbohydrates, glycerine, propylene glycol and ethyl alcohol, fats, and amino acids.[65,67-73] Unfortunately, today we can still only repeat the conclusion given there— that despite the importance of the problem, the results of numerous studies still concern only theoretical solutions of the problem and not concrete methods that can be applied in daily practice.

Next, the chapter considered the problem of obtaining food products as a result of biological production of food based on a partially or completely closed substance cycle. Such substance cycles occur naturally on the Earth. However, production of food products from wastes of crewmembers and the spacecraft biocomplex is evidently practical only for very long-term, completely autonomous flights or on long-duration stations.

The components of a recycling system on a spacecraft may be lower (one-celled algae) and higher autotrophic plants, lower heterotrophic organisms (yeasts, bacteria, and zooplankton), animal heterotrophic organisms (small animals and birds), humans; and a system of waste conversion.[63,65,74] Various combinations of biological and physicochemical methods for producing food are also possible. The previous edition of *Foundations of Space Biology and Medicine*[2] considered algae,[75-77] bacteria,[78,79] higher plants, [80,81] and fungi[80,82] in relative detail as potential sources of food in space.

Organisms capable of transforming human waste products into a nutritive biomass could theoretically also solve the problems of regenerating the cabin atmosphere and disposing of waste. In the opinion of certain researchers, autotrophic algae and bacteria are the most suitable organisms for a system of complete bioregeneration, considering the weight and volume required for this system. Higher plants may be grown hydroponically on large orbital and planetary stations, whereas animals may serve as an additional intermediate component of bioregeneration, requiring vegetable food.[76,81,83]

When the biomass obtained through regeneration of the atmosphere and wastes can supply a major portion of the diet, all that is required is to fine tune the system to match the elements of the bioregenerative system to the nutritional needs of the crewmembers. The food value of edible products obtained in a bioregenerative system are considered in detail in a special literature review.[84]

Bioregenerative systems for producing nutritive material must be supplemented with a technological system for processing them into products acceptable to cosmonauts in terms of taste and other aspects of palatability, as well as in terms of nutritive value.

There have certainly been some positive results toward solving the problem of bioregeneration of food. Work in this area is continuing; however, the successes are modest. Evidently, to create a reliable, complex, closed system for producing food in flight, especially ready-to-eat food and not just individual nutritive materials, an enormous amount of work still has to be done. Work in this area can be expected to intensify when space flights of 3 years and longer are scheduled, under which condition onboard systems based on food supplies would be seriously inferior to mixed or exclusively bioregenerative systems.

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